Parametric Study of Space Radiation Exposure for the OBPR-Heavy Missions.

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1. Orbits

A trajectory ephemeris was generated for nine orbital configurations. Three inclinations were selected ($30^0, 40^0, 60^0$) and three altitudes at each inclination (300 km, 500 km, 800 km), covering the low-altitude, low-inclination domain of interest to OBPR Heavy missions.

These orbits have periods ranging from about 90 to about 100 minutes. They complete about 14.5 to 16.0 revolutions per day, of which approximately half pass through the 'South Atlantic Anomaly' (SAA).

2. Mission Duration

A 60-day mission duration was specified for the evaluation of the radiation exposure. If a 90-day mission is a possible option, the corresponding doses can be approximated by adding 50% to the values obtained for the 60-day mission.

3. Environment Models

The NASA standard models of the space radiation environment (AP8 for protons and AE8 for electrons) were used to obtain the spacecraft incident radiation spectra. These are static models that have a Solar Minimum and a Solar Maximum version.

Their data are associated with significant uncertainty factors : the protons with a factor of 2, the electrons with a factor of 2-5.

4. Dose Calculations

Doses were calculated from the surface incident proton and electron fluxes, integrated over the 60-day mission duration. The calculations were performed for a spherical aluminum shield with thicknesses ranging from 1 mm to 10 mm (0.27 g/cm^2 to 2.70 g/cm^2), with a 4π exposure.

It should be noted, that the spherical geometry yields the worst case dose, as against a slab geometry (with a 4π exposure) that yields a lower dose. Actual satellite reality lies somewhere in between these extrema.

5. Results

A. Total Doses: The total doses from electrons, protons, and Bremsstrahlung on a biological target within the spacecraft, in units of rad-tissue, are shown in Figure 1 for the nine orbital configurations considered in this parametric study.

As would be expected, the trajectories of lowest altitude experience the smallest total dose levels, with the exception of the 60^0 inclination orbits. These flight paths are special in two ways :

a. at thin shield thicknesses they experience significantly greater doses , in comparison to the other orbits (for corresponding altitude), and

b. the contributions to the total dose from electrons dominates (is proportionally more significant) well up to thicknesses of 10 mm at 300 km (Figure 2), 8 mm at 500 km, and 6 mm at 800 km.

In all other cases, the proton contributions prevail above 5 mm shield thickness (Figure 3).

It may be of interest to observe that the Bremsstrahlung contributions are mostly negligible : they are usually one-to-two orders of magnitude smaller than the dominant proton doses at thicknesses greater than about 3 mm; but their importance increases with the prevalence of the electron contribution, being a maximum at the 60^0/300 km orbit.

B. Shield Thickness Effects: Above aluminum shield thickness of about 4-5 mm, additional shielding is of little gain in harsh radiation environments. For example, in the case of the two most exposed orbits (30^0/800 km and 40^0/800 km), the dose at 5 mm thickness is 1.294×10^3 and 1.253×10^3 rad-tissue, respectively. By increasing the shield thickness to 10 mm, that is doubling it, reduces the dose by only about 25% and 27%, respectively.

C. Geometry Effect : Total dose results obtained for a 4π exposure with the same mission integrated fluences are significantly lower for a "slab" geometry than for a "spherical" geometry. The difference for protons may be as large as a factor of 2-3, and for electrons as large as a factor of 6-7. Spacecraft reality lies somewhere in between.

D. Solar Cycle Effects: Total doses obtained from the NASA models for the investigated orbits are higher (at all shield thicknesses) for the solar-maximum period than for the solar-minimum, with the exception of two orbits:

a. Orbit 30^0/300 km for spherical shield thickness > 4 mm the solar-min values are larger than the solar-max, and

b. Orbit 60^0/300 km for spherical shield thickness > 7 mm the solar-min values are also larger than the solar-max.

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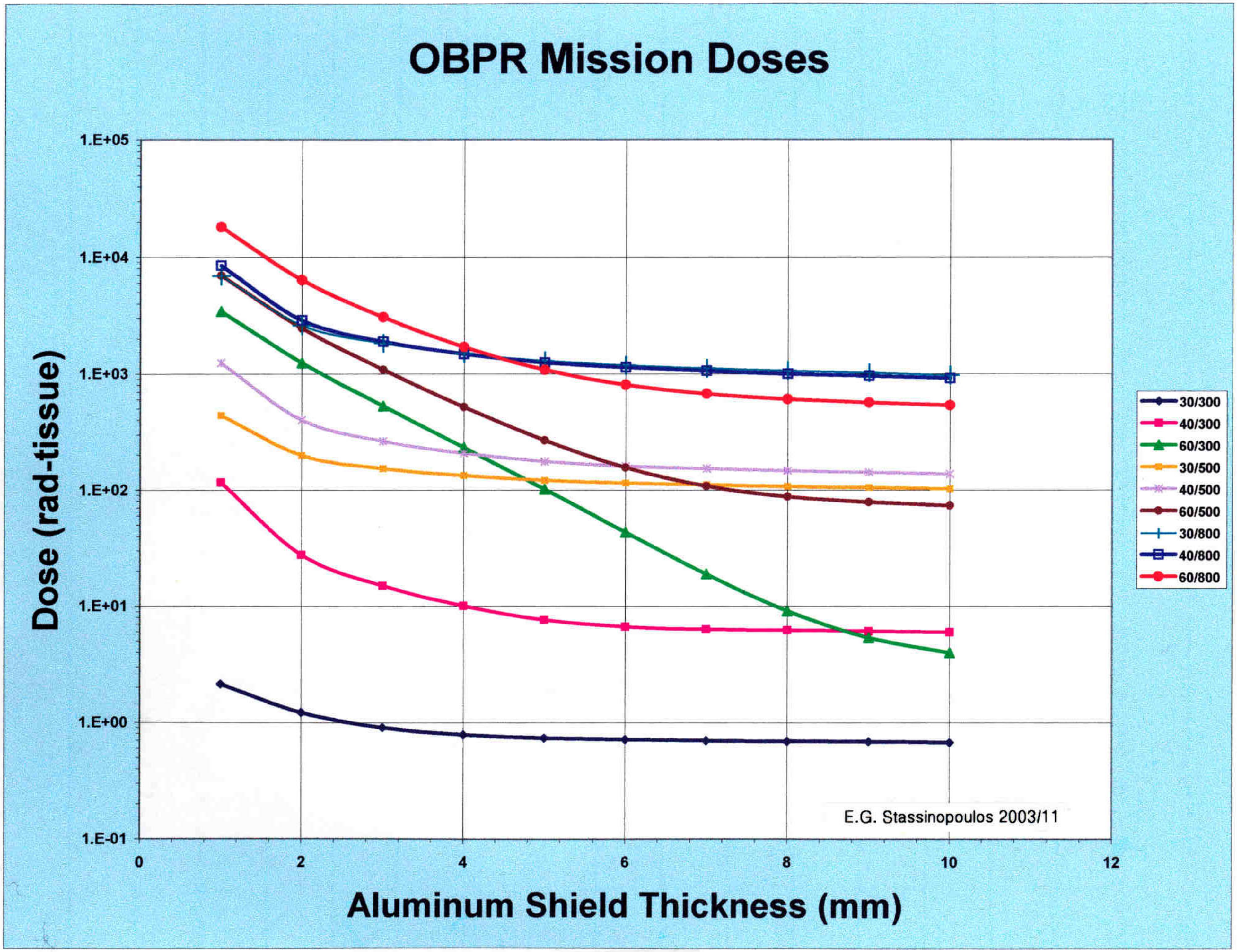

OBPR Mission Doses
Dose (rad-tissue)
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
2
4
6
8
10
12
Aluminum Shield Thickness (mm)
30/300
40/300
60/300
30/500
40/500
60/500
30/800
40/800
60/800
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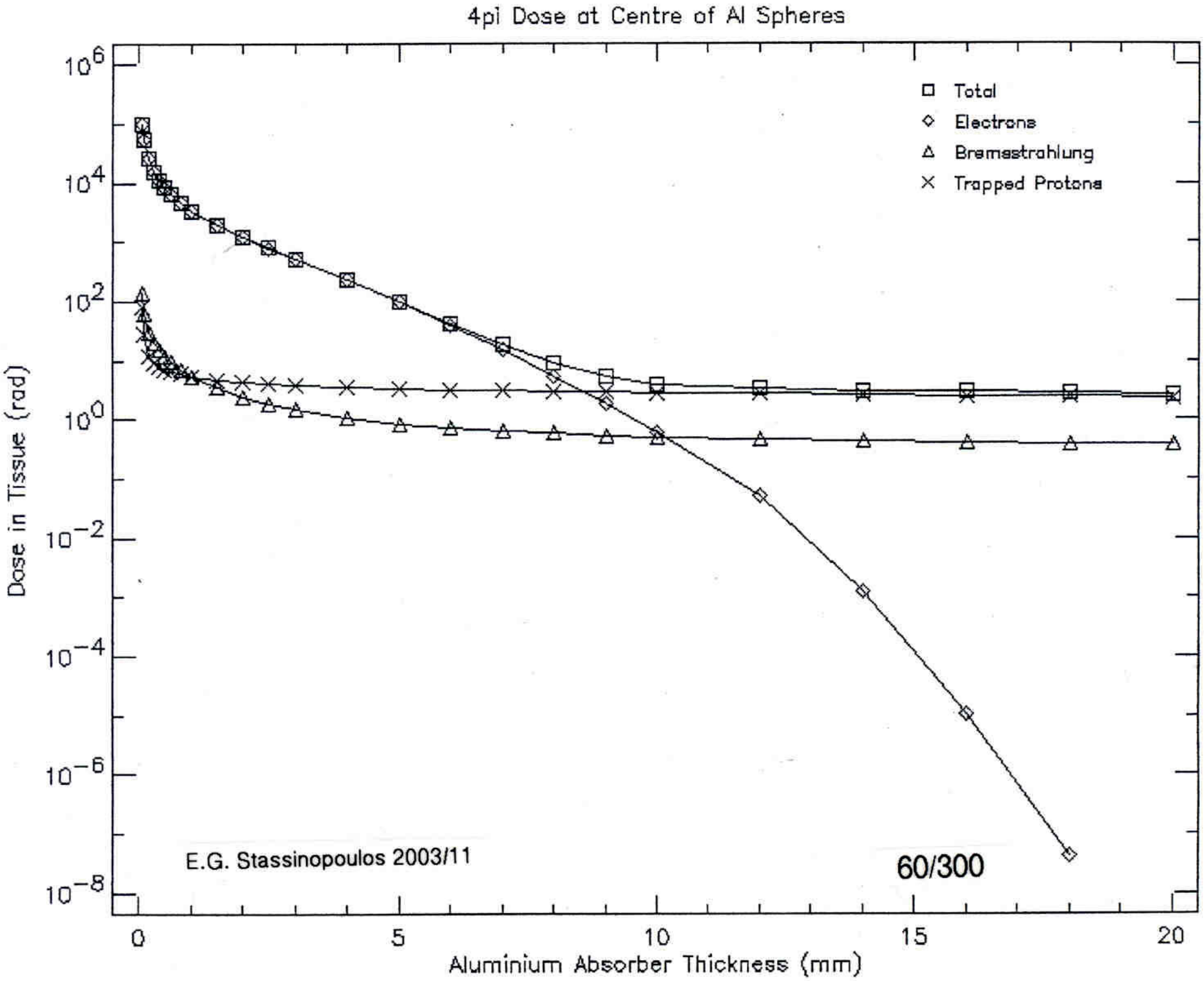
Figure 1



4pi Dose at Centre of Al Spheres
Total
Electrons
Bremsstrahlung
Trapped Protons
Dose in Tissue (rad)
Aluminium Absorber Thickness (mm)
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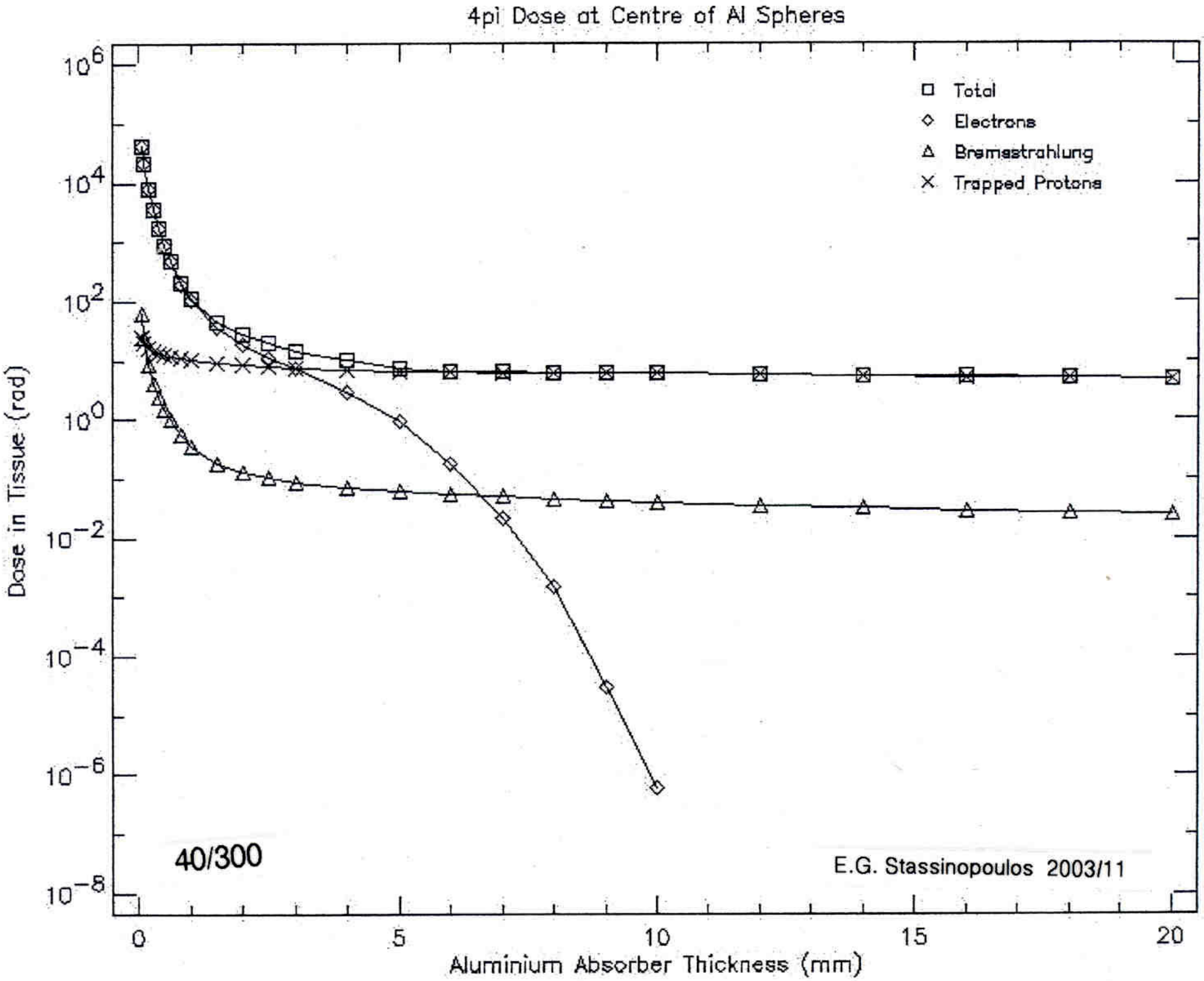
60/300

Figure 2


4pi Dose at Centre of Al Spheres
Total
Electrons
Bremsstrahlung
Trapped Protons
Dose in Tissue (rad)
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
40/300
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0
5
10
15
20
Aluminium Absorber Thickness (mm)

Figure 3